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(54) Title: SEEDED BOEHMITE PARTICULATE MATERIAL AND METHODS FOR FORMING SAME



(57) Abstract: A boehmite particulate material is disclosed. The material is formed by a process that includes providing a boehmite precursor and boehmite seeds in a suspension, and heat treating the suspension to convert the boehmite precursor into boehmite particulate material. The boehmite particulate material has an aspect ratio of not less than 3:1.

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SEEDED BOEHMITE PARTICULATE MATERIAL AND METHODS FOR FORMING SAME

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application is (i) a continuation-in-part application of US Patent Application 10/414,590, filed April 16, 2003, which in turn is a non-provisional application of US Provisional Application 60/374,014 filed April 19, 2002, and (ii) a continuation-in-part application of US Patent Application 10/823,400, filed April 13, 2004. Priority to the foregoing applications is hereby claimed, and the subject matter thereof hereby incorporated by reference.

BACKGROUND

Field of the Invention

[0002] The present invention generally relates to boehmite particulate material and processes for forming same. More specifically, the present invention relates to seeded boehmite particulate material having morphological features.

Description of the Related Art

[0003] Boehmite particulate material finds particular application as a desirable raw material for forming aluminous products, for example, alumina abrasive grains having high performance characteristics. In this context, the US Patent 4,797,139, commonly owned by the present Assignee, discloses a particular process for forming boehmite particulate material, which is then used as a feedstock material for later stage processing to form alumina abrasive grains. As described, the boehmite material is formed by a seeded process, and is limited in scope to boehmite particulate material that is adapted to form alumina abrasive grains. As such, the disclosed particulate

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material has particularly desired spherical morphology, which makes it suitable for abrasive applications.

[0004] Beyond abrasive applications, there is a particular desirability for creating boehmite particulate material having varying morphology. Since particulate morphology can have a profound impact upon the applications of the material, a need has arisen in the art for creation of new materials for applications beyond abrasives, including fillers utilized in specialty coating products and various polymer products. Other applications include those in which the boehmite material is utilized in its as-formed state, rather than as a feedstock material. In addition to the interest in creating new materials, processing technology enabling the formation of such materials needs to be developed as well. In this regard, such processing technology is desirably cost effective, is relatively straightforward to control, and provides high yields.

SUMMARY

[0005] According to one aspect, boehmite particulate material formed by seeded processing has an aspect ratio of not less than 3:1.

[0006] According to another aspect of the present invention, a boehmite particulate material is formed by a process that includes providing a boehmite precursor and boehmite seeds in a suspension, and heat treating the suspension to convert the boehmite precursor into boehmite particulate material. The particulate material may have a certain morphology, such as a relatively high aspect ratio, such as not less than about 2:1, such as not less than about 3:1.

[0007] Still further, according to another aspect of the present invention, boehmite particulate material is formed by a process including providing a boehmite precursor and boehmite seeds in a suspension, and heat-treating the suspension to convert the boehmite precursor into boehmite particulate material. Here, the boehmite particulate material is comprised of platelets, and has an aspect of not less than about 2:1.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is an SEM micrograph illustrating platelet-shaped boehmite particulate material.

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[0009] FIG. 2 is an SEM micrograph illustrating needle-shaped boehmite particulate material.

[0010] FIG. 3 is an SEM micrograph illustrating ellipsoid-shaped boehmite particulate material.

[0011] FIG. 4 is an SEM micrograph illustrating spherical-shaped boehmite particulate material.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0012] According to an embodiment of the present invention, a boehmite particulate material is formed by a process that includes providing a boehmite precursor and boehmite seeds in a suspension, and heat treating (such as by hydrothermal treatment) the suspension (alternatively sol or slurry) to convert the boehmite precursor into boehmite particulate material formed of particles or crystallites. According to a particular aspect, the boehmite particulate material has a relatively elongated morphology, described generally herein in terms of aspect ratio, described below.

[0013] The term "boehmite" is generally used herein to denote alumina hydrates including mineral boehmite, typically being $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$ and having a water content on the order of 15%, as well as psuedoboehmite, having a water content higher than 15%, such as 20-38% by weight. It is noted that boehmite (including psuedoboehmite) has a particular and identifiable crystal structure, and accordingly unique X-ray diffraction pattern, and as such, is distinguished from other aluminous materials including other hydrated aluminas such as ATH (aluminum trihydroxide) a common precursor material used herein for the fabrication of boehmite particulate materials.

[0014] The aspect ratio, defined as the ratio of the longest dimension to the next longest dimension perpendicular to the longest dimension, is generally not less than 2:1, and preferably not less than 3:1, 4:1, or 6:1. Indeed, certain embodiments have relatively elongated particles, such as not less than 9:1, 10:1, and in some cases, not less than 14:1. With particular reference to needle-shaped particles, the particles may be further characterized with reference to a secondary aspect ratio defined as the ratio of the second longest dimension to the third longest dimension. The secondary aspect

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ratio is generally not greater than 3:1, typically not greater than 2:1, or even 1.5:1, and oftentimes about 1:1. The secondary aspect ratio generally describes the cross-sectional geometry of the particles in a plane perpendicular to the longest dimension.

[0015] Platey or platelet-shaped particles generally have an elongated structure having the aspect ratios described above in connection with the needle-shaped particles. However, platelet-shaped particles generally have opposite major surfaces, the opposite major surfaces being generally planar and generally parallel to each other. In addition, the platelet-shaped particles may be characterized as having a secondary aspect ratio greater than that of needle-shaped particles, generally not less than about 3:1, such as not less than about 6:1, or even not less than 10:1. Typically, the shortest dimension or edge dimension, perpendicular to the opposite major surfaces or faces, is generally less than 50 nanometers.

[0016] Morphology of the boehmite particulate material may be further defined in terms of particle size, more particularly, average particle size. Here, the seeded boehmite particulate material, that is, boehmite formed through a seeding process (described in more detail below) has a relatively fine particle or crystallite size. Generally, the average particle size is not greater than about 1000 nanometers, and fall within a range of about 100 to 1000 nanometers. Other embodiments have even finer average particle sizes, such as not greater than about 800 nanometers, 600 nanometers, 500 nanometers, 400 nanometers, and even particles having an average particle size smaller than 300 nanometers, representing a fine particulate material.

[0017] As used herein, the "average particle size" is used to denote the average longest or length dimension of the particles. Due to the elongated morphology of the particles, conventional characterization technology is generally inadequate to measure average particle size, since characterization technology is generally based upon an assumption that the particles are spherical or near-spherical. Accordingly, average particle size was determined by taking multiple representative samples and physically measuring the particle sizes found in representative samples. Such samples may be taken by various characterization techniques, such as by scanning electron microscopy (SEM).

[0018] The present seeded boehmite particulate material has been found to have a fine average particle size, while oftentimes competing non-seeded based technologies are generally incapable of providing such fine average particle sizes. In this regard, it is noted that oftentimes in the literature, reported particle sizes are not set forth in the context of averages as in the present specification, but rather, in the context of nominal range of particle sizes derived from physical inspection of samples of the particulate material. Accordingly, the average particle size will lie within the reported range in the prior art, generally at about the arithmetic midpoint of the reported range, for the expected Gaussian particle size distribution. Stated alternatively, while non-seeded based technologies may report fine particle size, such fine sizing generally denotes the lower limit of an observed particle size distribution and not average particle size.

[0019] Likewise, in a similar manner, the above-reported aspect ratios generally correspond to the average aspect ratio taken from representative sampling, rather than upper or lower limits associated with the aspect ratios of the particulate material. Oftentimes in the literature, reported particle aspect ratios are not set forth in the context of averages as in the present specification, but rather, in the context of nominal range of aspect ratios derived from physical inspection of samples of the particulate material. Accordingly, the average aspect ratio will lie within the reported range in the prior art, generally at about the arithmetic midpoint of the reported range, for the expected Gaussian particle morphology distribution. Stated alternatively, while non-seeded based technologies may report aspect ratio, such data generally denotes the lower limit of an observed aspect ratio distribution and not average aspect ratio.

[0020] In addition to aspect ratio and average particle size of the particulate material, morphology of the particulate material may be further characterized in terms of specific surface area. Here, the commonly available BET technique was utilized to measure specific surface area of the particulate material. According to embodiments herein, the boehmite particulate material has a relatively high specific surface area, generally not less than about $10 \text{ m}^2/\text{g}$, such as not less than about $50 \text{ m}^2/\text{g}$, $70 \text{ m}^2/\text{g}$, or not less than about $90 \text{ m}^2/\text{g}$. Since specific surface area is a function of particle

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morphology as well as particle size, generally the specific surface area of embodiments was less than about $400 \text{ m}^2/\text{g}$, such as less than about 350 or $300 \text{ m}^2/\text{g}$.

[0021] Turning to the details of the processes by which the boehmite particulate material may be manufactured, generally ellipsoid, needle, or platelet-shaped boehmite particles are formed from a boehmite precursor, typically an aluminous material including bauxitic minerals, by hydrothermal treatment as generally described in the commonly owned patent described above, US Patent 4,797,139. More specifically, the boehmite particulate material may be formed by combining the boehmite precursor and boehmite seeds in suspension, exposing the suspension (alternatively sol or slurry) to heat treatment to cause conversion of the raw material into boehmite particulate material, further influenced by the boehmite seeds provided in suspension. Heating is generally carried out in an autogenous environment, that is, in an autoclave, such that an elevated pressure is generated during processing. The pH of the suspension is generally selected from a value of less than 7 or greater than 8, and the boehmite seed material has a particle size finer than about 0.5 microns. Generally, the seed particles are present in an amount greater than about 1% by weight of the boehmite precursor (calculated as Al_2O_3), and heating is carried out at a temperature greater than about 120°C , such as greater than about 125°C , or even greater than about 130°C , and at a pressure greater than about 85 psi, such as greater than about 90 psi, 100 psi, or even greater than about 110 psi.

[0022] The particulate material may be fabricated with extended hydrothermal conditions combined with relatively low seeding levels and acidic pH, resulting in preferential growth of boehmite along one axis or two axes. Longer hydrothermal treatment may be used to produce even longer and higher aspect ratio of the boehmite particles and/or larger particles in general.

[0023] Following heat treatment, such as by hydrothermal treatment, and boehmite conversion, the liquid content is generally removed, such as through an ultrafiltration process or by heat treatment to evaporate the remaining liquid. Thereafter, the resulting mass is generally crushed, such to 100 mesh. It is noted that the particulate size described herein generally describes the single crystallites formed through processing, rather than the aggregates which may remain in certain embodiments (e.g., for those products that call for and aggregated material).

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[0024] According to data gathered by the present inventors, several variables may be modified during the processing of the boehmite raw material, to effect the desired morphology. These variables notably include the weight ratio, that is, the ratio of boehmite precursor to boehmite seed, the particular type or species of acid or base used during processing (as well as the relative pH level), and the temperature (which is directly proportional to pressure in an autogenous hydrothermal environment) of the system.

[0025] In particular, when the weight ratio is modified while holding the other variables constant, the shape and size of the particles forming the boehmite particulate material are modified. For example, when processing is carried at 180°C for two hours in a 2 weight % nitric acid solution, a 90:10 ATH:boehmite seed ratio forms needle-shaped particles (ATH being a species of boehmite precursor). In contrast, when the ATH:boehmite seed ratio is reduced to a value of 80:20, the particles become more elliptically shaped. Still further, when the ratio is further reduced to 60:40, the particles become near-spherical. Accordingly, most typically the ratio of boehmite precursor to boehmite seeds is not less than about 60:40, such as not less than about 70:30 or 80:20. However, to ensure adequate seeding levels to promote the fine particulate morphology that is desired, the weight ratio of boehmite precursor to boehmite seeds is generally not greater than about 98:2. Based on the foregoing, an increase in weight ratio generally increases aspect ratio, while a decrease in weight ratio generally decreased aspect ratio.

[0026] Further, when the type of acid or base is modified, holding the other variables constant, the shape (e.g., aspect ratio) and size of the particles are affected. For example, when processing is carried out at 100°C for two hours with an ATH:boehmite seed ratio of 90:10 in a 2 weight % nitric acid solution, the synthesized particles are generally needle-shaped, in contrast, when the acid is substituted with HCl at a content of 1 weight % or less, the synthesized particles are generally near spherical. When 2 weight % or higher of HCl is utilized, the synthesized particles become generally needle-shaped. At 1 weight % formic acid, the synthesized particles are platelet-shaped. Further, with use of a basic solution, such as 1 weight % KOH, the synthesized particles are platelet-shaped. If a mixture of

acids and bases is utilized, such as 1 weight % KOH and 0.7 weight % nitric acid, the morphology of the synthesized particles is platelet-shaped.

[0027] Suitable acids and bases include mineral acids such as nitric acid, organic acids such as formic acid, halogen acids such as hydrochloric acid, and acidic salts such as aluminum nitrate and magnesium sulfate. Effective bases include, for example, amines including ammonia, alkali hydroxides such as potassium hydroxide, alkaline hydroxides such as calcium hydroxide, and basic salts.

[0028] Still further, when temperature is modified while holding other variables constant, typically changes are manifested in particle size. For example, when processing is carried out at an ATH:boehmite seed ratio of 90:10 in a 2 weight % nitric acid solution at 150°C for two hours, the crystalline size from XRD (x-ray diffraction characterization) was found to be 115 Angstroms. However, at 160°C the average particle size was found to be 143 Angstroms. Accordingly, as temperature is increased, particle size is also increased, representing a directly proportional relationship between particle size and temperature.

[0029] Example 1, Plate-shaped particle synthesis

[0030] An autoclave was charged with 7.42 lb. of Hydral 710 aluminum trihydroxide purchased from Alcoa; 0.82 lb of boehmite obtained from SASOL under the name-- Catapal B pseudoboehmite; 66.5 lb of deionized water; 0.037 lb potassium hydroxide; and 0.18 lb of 22wt% nitric acid. The boehmite was pre-dispersed in 5 lb of the water and 0.18 lb of the acid before adding to the aluminum trihydroxide and the remaining water and potassium hydroxide.

[0031] The autoclave was heated to 185°C. over a 45 minute period and maintained at that temperature for 2 hours with stirring at 530 rpm. An autogenously generated pressure of about 163 psi was reached and maintained. Thereafter the boehmite dispersion was removed from the autoclave. After autoclave the pH of the sol was about 10. The liquid content was removed at a temperature of 65°C. The resultant mass was crushed to less than 100 mesh. The SSA of the resultant powder was about 62 m²/g.

[0032] Example 2, Needle-shaped particle synthesis

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[0033] An autoclave was charged with 250 g of Hydral 710 aluminum trihydroxide purchased from Alcoa; 25 g of boehmite obtained from SASOL under the name-- Catapal B pseudoboehmite; 1000 g of deionized water; and 34.7 g of 18% nitric acid. The boehmite was pre-dispersed in 100 g of the water and 6.9 g of the acid before adding to the aluminum trihydroxide and the remaining water and acid.

[0034] The autoclave was heated to 180°C. over a 45 minute period and maintained at that temperature for 2 hours with stirring at 530 rpm. An autogenously generated pressure of about 150 psi was reached and maintained. Thereafter the boehmite dispersion was removed from the autoclave. After autoclave the pH of the sol was about 3. The liquid content was removed at a temperature of 95°C. The resultant mass was crushed to less than 100 mesh. The SSA of the resultant powder was about 120 m²/g.

[0035] Example 3, Ellipsoid shaped particle synthesis

[0036] An autoclave was charged with 220 g of Hydral 710 aluminum trihydroxide purchased from Alcoa; 55 g of boehmite obtained from SASOL under the name-- Catapal B pseudoboehmite; 1000 g of deionized water; and 21.4 g of 18% nitric acid. The boehmite was pre-dispersed in 100 g of the water and 15.3 g of the acid before adding to the aluminum trihydroxide and the remaining water and acid.

[0037] The autoclave was heated to 172°C. over a 45 minute period and maintained at that temperature for 3 hours with stirring at 530 rpm. An autogenously generated pressure of about 120 psi was reached and maintained. Thereafter the boehmite dispersion was removed from the autoclave. After autoclave the pH of the sol was about 4. The liquid content was removed at a temperature of 95°C. The resultant mass was crushed to less than 100 mesh. The SSA of the resultant powder was about 135 m²/g.

[0038] Example 4, Near Spherical Particle synthesis

[0039] An autoclave was charged with 165 g of Hydral 710 aluminum trihydroxide purchased from Alcoa; 110 g of boehmite obtained from SASOL under the name-- Catapal B pseudoboehmite; 1000 g of deionized water; and 35.2 g of 18% nitric acid.

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The boehmite was pre-dispersed in 100 g of the water and 30.6 g of the acid before adding to the aluminum trihydroxide and the remaining water and acid.

[0040] The autoclave was heated to 160°C. over a 45 minute period and maintained at that temperature for 2.5 hours with stirring at 530 rpm. An autogenously generated pressure of about 100 psi was reached and maintained. Thereafter the boehmite dispersion was removed from the autoclave. After autoclave the pH of the sol was about 3.5. The liquid content was removed at a temperature of 95°C. The resultant mass was crushed to less than 100 mesh. The SSA of the resultant powder was about 196 m²/g.

[0041] According to embodiments described herein, a relatively powerful and flexible process methodology may be employed to engineer desired morphologies into the final boehmite product. Of particular significance, embodiments utilize seeded processing resulting in a cost-effective processing route with a high degree of process control which may result in desired fine average particle sizes as well as controlled particle size distributions. The combination of (i) identifying and controlling key variables in the process methodology, such as weight ratio, acid and base species and temperature, and (ii) seeding-based technology is of particular significance, providing repeatable and controllable processing of desired boehmite particulate material morphologies.

[0042] Aspects of the present invention enable utilization of the boehmite particulate material in a wide variety of applications, such as a filler in specialty coatings as well as in polymer products. Indeed, the particulate material may be individually and uniformly dispersed within solvents (particularly including polar solvents), and/or polymers without forming aggregates by conventional compounding processes. In addition, the boehmite particulate material may be individually and uniformly dispersed with a non-polar solvents, and/or polymers without forming aggregates by utilizing conventional dispersing agents such as silane coupling agents. Of course, particular applications of the boehmite particulate material are not so limited and may find commercial use in a variety of applications.

[0043] While the invention has been illustrated and described in the context of specific embodiments, it is not intended to be limited to the details shown, since

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various modifications and substitutions can be made without departing in any way from the scope of the present invention. For example, additional or equivalent substitutes can be provided and additional or equivalent production steps can be employed. As such, further modifications and equivalents of the invention herein disclosed may occur to persons skilled in the art using no more than routine experimentation, and all such modifications and equivalents are believed to be within the scope of the invention as defined by the following claims.

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WHAT IS CLAIMED IS:

1. A boehmite particulate material formed by a process comprising:
providing a boehmite precursor and boehmite seeds in a suspension; and
heat treating the suspension to convert the boehmite precursor into boehmite
particulate material, the boehmite particulate material having an aspect
ratio of not less than 3:1.
2. The material of claim 1, wherein the aspect ratio is not less than 4:1.
3. The material of claim 2, wherein the aspect ratio is not less than 6:1.
4. The material of claim 3, wherein the aspect ratio is not less than 9:1.
5. The material of claim 1, wherein the boehmite particulate material
predominantly comprises platelet-shaped particles, having a secondary aspect ratio of
not less than 3:1.
6. The material of claim 5, wherein the secondary aspect ratio is not less than
6:1.
7. The material of claim 6, wherein the secondary aspect ratio is not less than
10:1.
8. The material of claim 1, wherein the boehmite particulate material
predominantly comprises needle-shaped particles.
9. The material of claim 8, wherein the needle-shaped particles have a
secondary aspect ratio of not greater than 3:1.
10. The material of claim 9, wherein the secondary aspect ratio is not greater
than 2:1.
11. The material of claim 1, wherein the average particle size is not greater
than 1000 nm.

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12. The material of claim 11, wherein the average particle size is between about 100 and 1000nm.
13. The material of claim 11, wherein the average particle size is not greater than 800 nm.
14. The material of claim 13, wherein the average particle size is not greater than 600 nm.
15. The material of claim 14, wherein the average particle size is not greater than 500 nm.
16. The material of claim 15, wherein the average particle size is not greater than 400 nm.
17. The material of claim 16, wherein the average particle size is not greater than 300 nm.
18. The material of claim 1, wherein the boehmite particulate material has a specific surface area of not less than about 10 m²/g.
19. The material of claim 18, wherein the specific surface area of not less than about 50 m²/g.
20. The material of claim 19, wherein the specific surface area of not less than about 70 m²/g.
21. The material of claim 20, wherein the specific surface area of not greater than about 400 m²/g.
22. Boehmite particulate material formed by seeded processing in which a boehmite precursor is processed into boehmite by introduction of boehmite seed material and subsequent heat treatment, the boehmite particulate material having an aspect ratio of not less than 3:1.

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23. The material of claim 22, wherein the aspect ratio is not less than 4:1.
24. The material of claim 23, wherein the aspect ratio is not less than 6:1.
25. The material of claim 24, wherein the aspect ratio is not less than 9:1.
26. The material of claim 22, wherein the boehmite particulate material predominantly comprises platelet-shaped particles, having a secondary aspect ratio of not less than 3:1.
27. The material of claim 26, wherein the secondary aspect ratio is not less than 6:1.
28. The material of claim 27, wherein the secondary aspect ratio is not less than 10:1.
29. The material of claim 22, wherein the boehmite particulate material predominantly comprises needle-shaped particles.
30. The material of claim 29, wherein the needle-shaped particles have a secondary aspect ratio of not greater than 3:1.
31. The material of claim 30, wherein the secondary aspect ratio is not greater than 2:1.
32. The material of claim 22, wherein the average particle size is not greater than 1000 nm.
33. The material of claim 32, wherein the average particle size is between about 100 and 1000nm.
34. The material of claim 32, wherein the average particle size is not greater than 800 nm.

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35. The material of claim 34, wherein the average particle size is not greater than 600 nm.

36. The material of claim 35, wherein the average particle size is not greater than 500 nm.

37. The material of claim 36, wherein the average particle size is not greater than 400 nm.

38. The material of claim 37, wherein the average particle size is not greater than 300 nm.

39. The material of claim 22, wherein the boehmite particulate material has a specific surface area of not less than about 10 m²/g.

40. The material of claim 39, wherein the specific surface area of not less than about 50 m²/g.

41. The material of claim 40, wherein the specific surface area of not less than about 70 m²/g.

42. The material of claim 41, wherein the specific surface area of not greater than about 400 m²/g.

43. A method for forming boehmite particulate material, comprising:
providing a boehmite precursor and boehmite seeds in a suspension; and
heat treating the suspension to convert the boehmite precursor into boehmite
particulate material, the boehmite particulate material having an aspect
ratio of not less than 3:1.

44. The method of claim 43, wherein heat treating is carried out at a temperature greater than about 120°C.

45. The method of claim 44, wherein heat treating is carried out at a temperature greater than about 130°C.

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46. The method of claim 43, wherein heat treating is carried out at a pressure greater than about 85 psi (100psi).

47. The method of claim 43, wherein a weight ratio of boehmite precursor to boehmite seeds is not less 60:40.

48. The method of claim 47, wherein the weight ratio is not less than 80:20.

49. The method of claim 48, wherein a weight ratio of boehmite precursor to boehmite seeds is not greater than 98:2.

50. The method of claim 43, wherein the boehmite particulate material has an average particle size of not greater than about 1000 nm.

51. The method of claim 43, further including setting at least one of heat treatment temperature, type of acid or base in the suspension, or weight ratio of boehmite precursor to boehmite seeds such that the boehmite particulate material has an aspect ratio of not less than 3:1 and an average particle size not greater than 1000 nm.

52. The method of claim 51, wherein the acid or base is chosen from the group consisting of mineral acids, organic acids, halogen acids, acidic salts, amines, alkali hydroxides, alkaline hydroxides, and basic salts.

53. The method of claim 51, wherein setting includes modifying at least one of heat treatment temperature, type of acid or base, or ratio of boehmite precursor to boehmite seeds.

54. The method of claim 53, wherein the ratio of boehmite precursor to boehmite seeds is increased to increase aspect ratio, or decreased to decrease aspect ratio.

55. The method of claim 53, wherein the heat treatment temperature is increased to increase particle size, or decreased to reduce particle size.

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56. The method of claim 53, wherein the type of acid or base is modified to modify aspect ratio.

57. Boehmite particulate material formed by a process, comprising:
providing a boehmite precursor and boehmite seeds in a suspension; and
heat treating the suspension to convert the boehmite precursor into boehmite
particulate material comprised of platelets, the boehmite particulate
material having an aspect ratio of not less than 2:1.

58. The material of claim 57, wherein the platelets have a secondary aspect
ratio of not less than 3:1.

59. The material of claim 58, wherein the platelets have a secondary aspect
ratio of not less than 6:1.

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FIG. 1

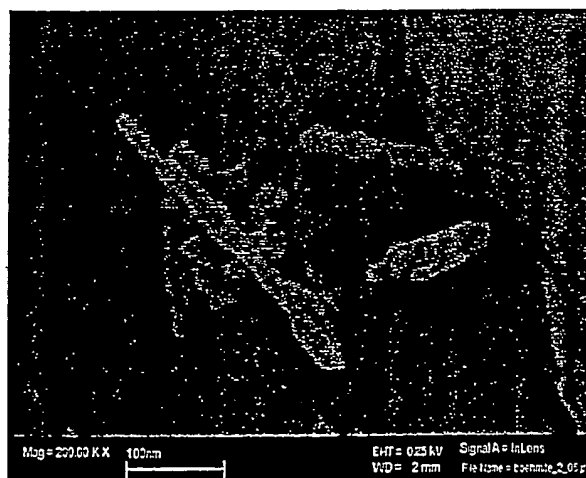


FIG. 2

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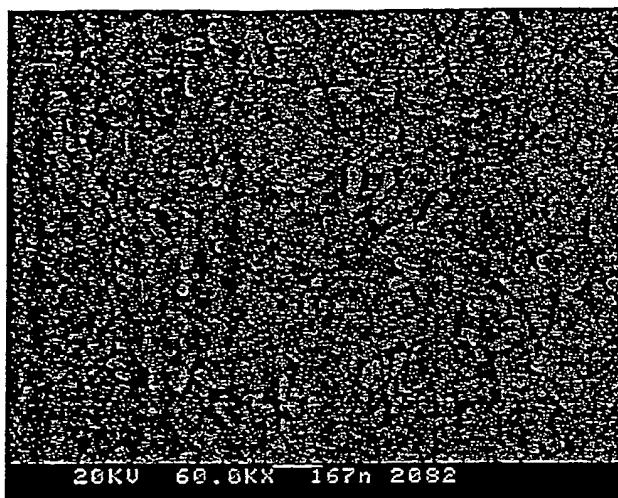


FIG. 3

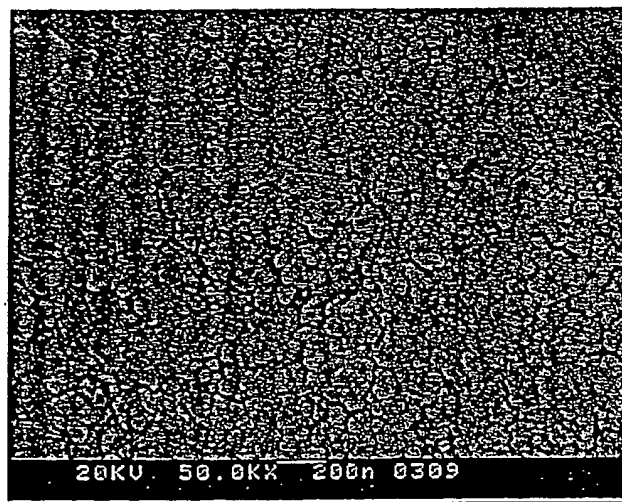


FIG. 4

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